Low Cost, Combination RF and Electrostatic Ferrite Device Protection for Electroexplosive Devices

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Abstract: ATI has developed a series of low cost, RF protection devices that are used inside electroexplosive devices (EEDs). The first series provided only RF protection using MN 67 Ferrite Formulation manufactured into ferrite beads, baluns, and chokes. An improved Ferrite Formulation, MN 68™, provides both RF and electrostatic (ES) protection in the same types of ferrite devices. Now that ATI better understands the EED protection theories, any ferrite that meets an ATI generic specification can be used to provide the combination RF and ES protection.

ATI can provide Certified Ferrite Devices that meet the performance characteristics of devices that previously passed MIL STD 1385B field tests in a wide variety of EED applications. These measurements and certifications can be done at three points in the ferrite device production cycle. The first is on the bare ferrite device before it is wound. The second is after the ferrite device has been wound with the appropriate winding pattern to attenuate to the required RF attenuation level. The third point is after the wound ferrite device is permanently installed in the EED. ATI retains samples of each lot of ferrite devices that has passed MIL STD 1385B field testing as baseline standards for certification of subsequent production lots.

ATI has a very strong intellectual property rights position in the combination RF and ES EED protection area. The first, US Patent 4,378,738, covers MN 67 applications. The second, US Patent 5,036,768 covers MN 68™ applications and is the first of several continuation-in-part patents. Eight other US Patent Applications cover specific applications, different winding patterns, measurement methods, and applications outside of the EED areas. Overseas patent protection is in process. ATI has also applied for USA Trade Marks and Certification Marks on these devices to assure proper identification of the devices that have passed this rigorous inspection and certification procedure.

ATI first buys large lots of ferrite formulation powder in order to certify that the formulation is correct before any ferrite devices are produced. Manufacturers then produce ferrite devices solely for ATI that operate within ATI specification limits. The USA companies have a combined production capacity exceeding 50,000,000 ferrite devices per year. There is a parallel commercial winding contractor with corresponding capability. Pilot production lots as large as 25,000 bare ferrite devices have been successfully produced for and certified by ATI.

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Background: For many years the potential for a simple, low cost ferrite device solution to solve the problem of inadvertent ignition of EED by stray RF energy has proved elusive. Now that the physical principles required for selecting first the ferrite formulation and then the ferrite device are understood, the technical solution has become clear and relatively simple. Prior to that understanding, many of us were on the wrong track with the selection of the ferrite formulation, the type of ferrite device required, its winding pattern, and the installation method in the EED.

New Ferrite Device Requirements: The first requirement is that there be no adhesive between the attenuating ferrite device and the EED's conductive case thereby providing good electrical contact between the two items. This contact also allows heat transfer to take place between the active ferrite and the heat radiator provided by the EED's metal case.

The second requirement is that the lead wires passing through the ferrite device must be bare and make good contact with the ferrite device. Without insulation there is no need to worry about long term insulation failure on the new generation of EEDs. Having bare lead wires allows the designer to take full advantage of the electrical properties to the ferrite to provide high impedance to incoming RF energy and to equalize the ES potential.

The third requirement is that the ferrite formulation have certain critical properties. These include:

1. A high Curie Temperature. Curie temperatures above 250^{o}C are required for EEDs without heat sinks. Several commercially available ferrite formulations have Curie Temperatures of 250^{o} or higher. ATI also has samples of these ferrites from overseas.

2. The RF attenuation starts at low frequencies. The ferrite formulation should start providing appreciable RF attenuation at frequencies no higher than 1 megahertz. Several of the newer ferrite formulations begin to be effective below 200 kilohertz. ATI is working on getting even lower actuation frequencies.

3. The ferrite devices have a DC resistance that is controlled within specified limits. If the DC resistance is too low, the EED's DC firing signal will not meet the all-fire and no-fire requirements. Prior to ATI's starting work in this area, all ferrites used for EED applications were considered to be nonconducting, or were installed with adhesives to electrically insulate them from the conductive case.

The fourth requirement is that the ferrite device must provide the correct conductor pattern. The ferrite device must be wound in such a manner to provide broad band RF protection from broadcast frequencies of one megahertz through radar frequencies in the gigahertz regions without any resonant frequencies.

Resonant frequencies would require providing additional electronic devices to protect those frequencies. These winding patterns have been demonstrated and independently verified by Franklin Research Center testing and reports. The second part of the winding pattern requirement is that it must provide sufficient RF attenuation to pass the RF attenuation specification over the entire frequency range. As an example, the ATI patented ferrite choke winding patterns are the only ones that will provide sufficient attenuation for an EED with exposed wire firing leads to pass MIL STD 1385B requirements. Improperly wound ferrite chokes will not pass MIL STD 1385B tests, and neither will single hole ferrite beads or two hole ferrite balun devices, even if they are stacked in series.

Types of Protection Provided: Once these four ferrite device requirements were met, it was determined that:

1. The wound ferrite device provided RF protection both pin-to-pin and pin-to-case over the required frequency range without any significant resonant frequencies.

2. The ferrite device provided protection against both intermittent and continuous RF energy sources.

3. One small ferrite device positioned inside the conductive case could provide all of the protection required.

4. If properly selected, the ferrite device could also provide protection against stray ES energy inadvertently initiating the EED. The ES protection was also determined to be for both pin-to-pin and pin-to-case energy inputs. The ferrite devices were also determined to be able to withstand repeated ES exposures without changing performance as some other ES protection devices do. The ferrite devices were able to survive higher ES potentials and higher power levels than other ES protective devices. The ferrite devices appear to absorb the ES energy and then bleed it out slowly in a controlled manner over large contact areas and over longer time frames.

5. The combined RF and ES protection can be provided for two wire and single wire EEDs. Examples of the two wire systems include the Mk 11 Mod 0 Electric Blasting Cap (EBC) and the Mk 20 Mod 0 Electric Squib. Both EOD Firing Line Filters are examples of one wire systems wound on MN 67 Ferrite Choke cores to provide the level of RF attenuation required for firing lines almost one mile long. The EOD firing line filters are used with the Mk 209 Mod 0 Cartridges. All of the systems listed above have been field tested to MIL STD 1385B requirements by the US Navy and are designated as HERO Safe, even though they all have exposed metal firing leads or long firing lines.

6. The ferrite protection device can be located either in the EED itself or in the firing line, if the remaining portion of

the firing line, between the ferrite device and the EED, is properly shielded. Because of the low unit cost, in most cases it is a lower cost approach to put the ferrite device in the EED and destroy it with each use, than it is to have a reusable ferrite device and shield the firing lead from the ferrite to the EED.

These results have been independently verified by Franklin Research Center reports issued over the last 14 years while this technology was slowly evolving. Within the last three years other companies have independently verified the performance of this new technology as their EEDs progressed through the R&D development process.

Levels of RF Protection Provided: Franklin Research Center determined that the Mk 11 Mod 0 EBC with MN 67 Ferrite Choke withstood 4 watts of continuously matched impedance RF energy for 5 minutes at 1 megahertz without firing (Ref. 1).

Franklin Research Center determined that the Mk 11 Mod 0 EBC with the MN 68™ Ferrite Choke in place of the MN 67 Ferrite Choke withstood 19 watts of continuously matched impedance RF energy for 5 minutes at 1 megahertz without firing (Ref 2).

As ATI better understood the requirements for combined RF & ES protection, the EED protection levels achieved have improved markedly. Franklin Research Center has not tested ATI generic ferrite formulations yet, but ATI is looking for financial assistance to test these new formulations to determine how they compare to MN™ 68 Ferrite Chokes.

New Applications for ATI Ferrite Devices: The ATI protection technologies were known to be suitable for applications using bridgewire ignition EED designs as early as 1981. Recently, ATI has been working with Thiokol Corporation to determine if the ATI protection technologies are applicable to other ignition systems such as SCB precision firing ignition devices disclosed in US 4,708,060. Thiokol is investigating using an ATI Ferrite Device in combination with the SCB for the MK 66 Igniter application. While written test reports have not been made available, verbal reports from the USN stated that the Thiokol R&D version of the Mk 66 Igniter passed MIL STD 1385B testing. As of the preparation date for this paper, the electrostatic testing has not been accomplished. One of the concerns of using the ATI Ferrite Device with the SCB was that the DC firing pulse, being only microseconds long, would be attenuated by the ATI Ferrite Device. Reproducible firing of the combination SCB device has, so far, not been a problem. Additional tests are planned by Thiokol.

Other new EED applications are in various stages of R&D development. Projects include on-board, aircraft engine fire extinguishers; electric blasting caps; cartridge actuated

devices; and precision firing, ignition modules. Since ATI is only supplying the ferrite protection devices for these projects, it will be left to the developer of each of these devices to report on details of their projects. The really significant result derived from all of these projects is that the ATI technologies appear to have broad applications beyond the initial bridgewire application projects reported and referenced by FRC above and further amplified in this report.

Any new ferrite device can be manufactured by pressing the ferrite formulation using paired dies and stakes specific to each application. The die is used to produce the ferrite device's outside diameter and length. The stake is used to produce the hole pattern. Any reasonable diameter, length, and hole pattern can be produced. ATI laboratory tests using MN 68™ Ferrite Devices indicate that wound chokes as small as 3 mm in diameter and 3 mm long should be sufficient to pass MIL STD 1385B requirements. The current ferrite devices are made larger to fit the inside diameter of the EED.

Current lead time for new tooling is about 12 weeks. Another method for obtaining R&D samples is to grind down existing ferrite devices. Both the overall length and outside diameter have been successfully ground down. ATI recommends that process be left to experts to get as representative samples to production items as possible. Samples can be obtained in about 4 weeks using the specialty grinding method.

<u>ATI Intellectual Property Rights</u>: ATI has the following USA intellectual property rights:

1. USA Patent 4,378,738 covers all aspects of using ferrite formulation MN 67 and its devices in EED applications.

2. USA Patent 5,036,768 covers all aspects of using ferrite formulation MN 68™ and its devices in EED applications. This is the main patent for a continuing series of continuation-in-part patent applications.

3. ATI has applied for a Registered US Trade Mark on MN 68. This is official recognition that MN 68™ Ferrite Formulation is unique and can not be copied by other ferrite manufacturers, users, or suppliers.

4. ATI has applied for a Certification Mark to differentiate ATI Certified Ferrite Devices from all others. The methods of measuring these devices is patent protected, the lot certification record keeping unmatched, and the certification process unique.

Not only has ATI applied for USA intellectual property rights protection, it is also filing for selected overseas protection.

As an example, ATI's first South African Patent should issue any day. South Africa is one of the major users of explosives in the world and is undertaking a major increase in protection levels for shallow mining activities.

ATI intends to fully enforce and defend any infringements of its intellectual property rights whatsoever.

<u>ATI Patent Applications Pending</u>: ATI has the following Patent Applications pending:

1. The use of generic specification ferrite formulations for combined RF & ES Protection for all EED Applications;

2. The use of generic ferrite devices in all EED applications;

3. On-line, 100% sampling for RF and other acceptance testing of ATI protected EEDs while still on the assembly line with an optional record keeping capability;

4. Combined RF & ES protection for specific EED applications;

5. Combined RF & ES protection for bridgewire and SCB initiators applications;

6. EEDs resistant to nearby lightning strikes;

7. Multiple, combined function ferrite devices;

8. RF & ES Protection for commercial electronic equipment.

Other patent applications are in preparation as our new technologies are further developed and new applications become evident.

<u>Products and Services Available from ATI</u>: ATI can provided Certified MN 67 Ferrite Chokes as both the bare cores and properly wound and functional ferrite chokes. MN 67 Chokes that previously passed MIL STD 1385B Certification in the Mk 11 Mod 0 EBC and Mk 20 Mod 0 Electric Squib are in the baseline certification program.

The exact same devices and certifications are available for the MN 68™ Devices. ATI is encouraging all projects to use MN 68™ Ferrite Devices in place of the MN 67 versions, since the MN 68™ Ferrite Devices are in stock, are now lower cost, provide combined RF & ES protection, and provide a greater safety margin when used in EED applications compared to MN 67 versions.

ATI Certified Ferrite Devices can be provided as bare ferrite cores or correctly wound ferrite devices. ATI inspection can be performed on the bare cores, on the wound choke before insertion into the EED, or on the explosively loaded, all-up EED using a combination of RF and DC energy.

Direct engineering support, technical support, and consultation services are also available from ATI to support new design work, R&D development programs, producing ferrite devices for specific applications, providing samples for evaluation among others.

<u>Production Quantities & Certification Available</u>: The largest lot that ATI has purchased and certified is 25,000 units of bare ferrite devices. The low quantities are not limited by capacity of any manufacturer or qualified ferrite formulation, but primarily because the current development programs are small and require the lower numbers to complete the project.

Early in the development cycle for the ferrite devices, ATI decided not to be limited to one ferrite formulation supplier or ferrite device manufacturer. It was difficult, time consuming, and costly to get multiple suppliers when the market was very small. Having multiple, qualified sources will pay off as the number of applications and quantities of ferrite devices required increase. With multiple, qualified sources, competition will tend to keep prices lower and delivery dates shorter.

ATI has already made the investment for the production tooling required to produce ferrite cores to NAVSEA 5206533 drawing requirements. For ferrite devices similar to NAVSEA 5206533, the combined estimated production capacity is 50,000,000 devices per year. That yearly capacity could be increased, if required, with as little as one year notice.

The unit cost goal of $0.28 each for the bare core quantities of 1,000,000 per year currently appear achievable. Also, ATI is already investigating ways to lower the unit cost. Since MN 68™ Devices have such large safety margins, it may be possible to:

1. Decrease the length of the bare core

2. Decrease the diameter of the bare core

3. Loosen dimensional tolerances on the bare core

4. Simplify the design by changing the hole pattern and progressing to a cylindrical design.

<u>In-house ATI Projects</u>: ATI is conducting a number of in-house, internally funded efforts to:

1. Provide automatic winding of the ferrite devices to lower the unit price of the wound ferrite chokes

2. Provide winding patterns to minimize or eliminate welds or solder joints in the wound EED firing leads

3. Provide complete assemblies including firing leads, wound ferrite device and initiation mechanism ready for insertion into the EED.

Summary: ATI has expanded their technology to include the use of MN™ 68 Ferrite Devices as a combined RF and ES protection improved replacement for the MN 67 Ferrite Devices previously reported. ATI has developed a generic specification to provide combined RF and ES protection for EEDs using any ferrite formulation meeting those requirements. ATI can provide certified ferrite devices that have the same performance as those previously passing MIL STD 1385B field testing. ATI has extensive intellectual property rights in this combined protection area including issued patents, patent applications, trade marks and certification marks for their ferrite devices.

References:

1. J. Heffron, "RF and Electrostatic Testing of Detonators" Franklin Research Center Technical Report F-C5067 December 1979

2. J. Stuart, "Tests on RF-Protected Blasting Caps Mark 11 Mod 0" Franklin Research Center Final Report P247 October 1990